

Recent cloudy sky photon path pdf measurements from Heidelberg

K. Pfeilsticker, and T. Scholl, IUP, University of Heidelberg, Germany

A. B. Davis, LANL, Los Alamos, USA

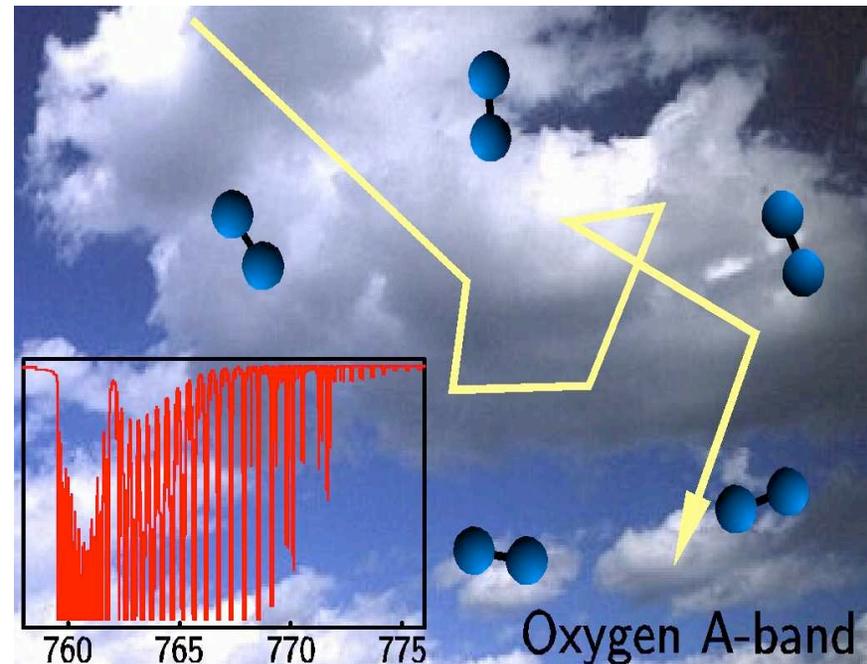
H. K. Baltink, KNMI, Utrecht, NL

S. Crewell, U. Löhnert, and C. Simmer, Met. Institute Bonn, Germany

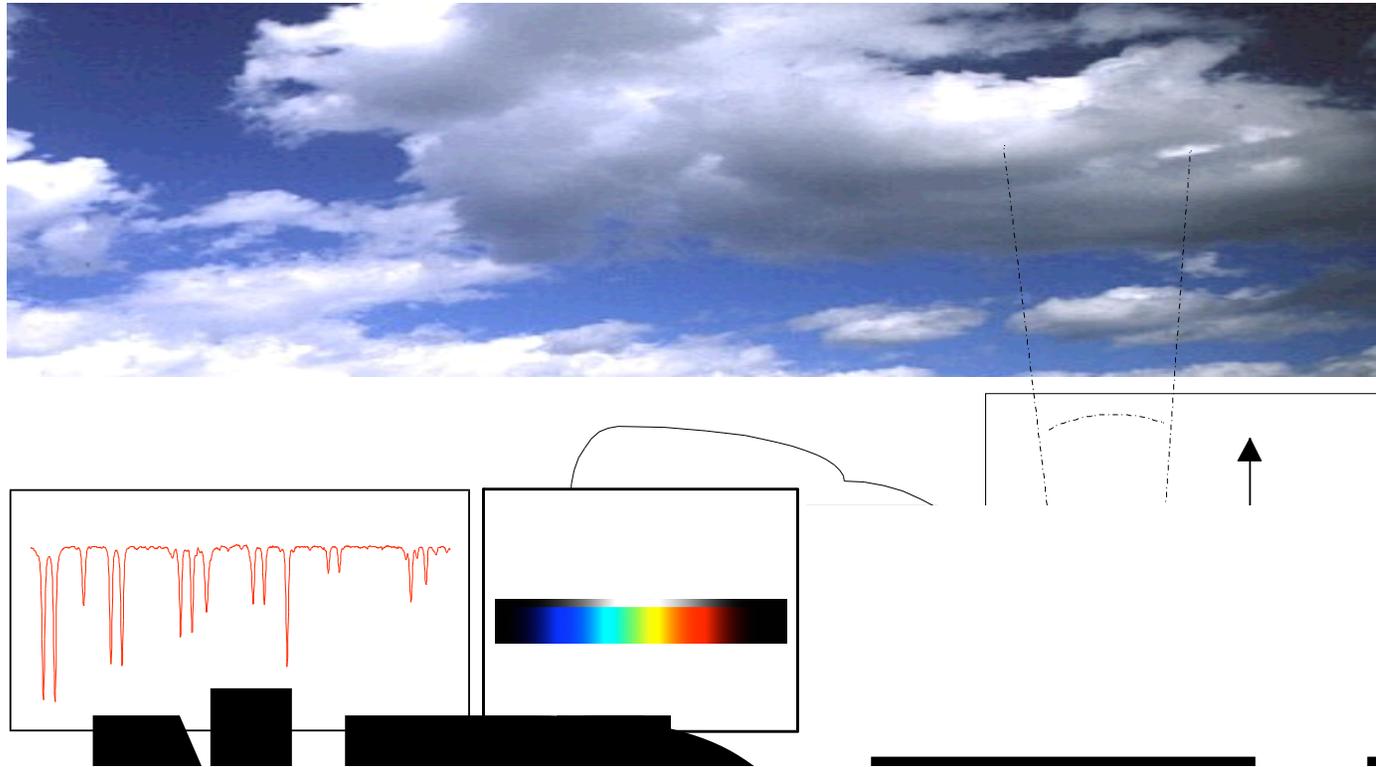
J. Meywerk, and M. Qante, GKSS, Geesthacht, Germany

Overview

- introduction
- oxygen A-band spectroscopy and retrieval technique
- some examples
- Test of
 - photon diffusion in plane-parallel cloud geometry
 - real clouds (anomalous diffusion)
- summary and conclusion



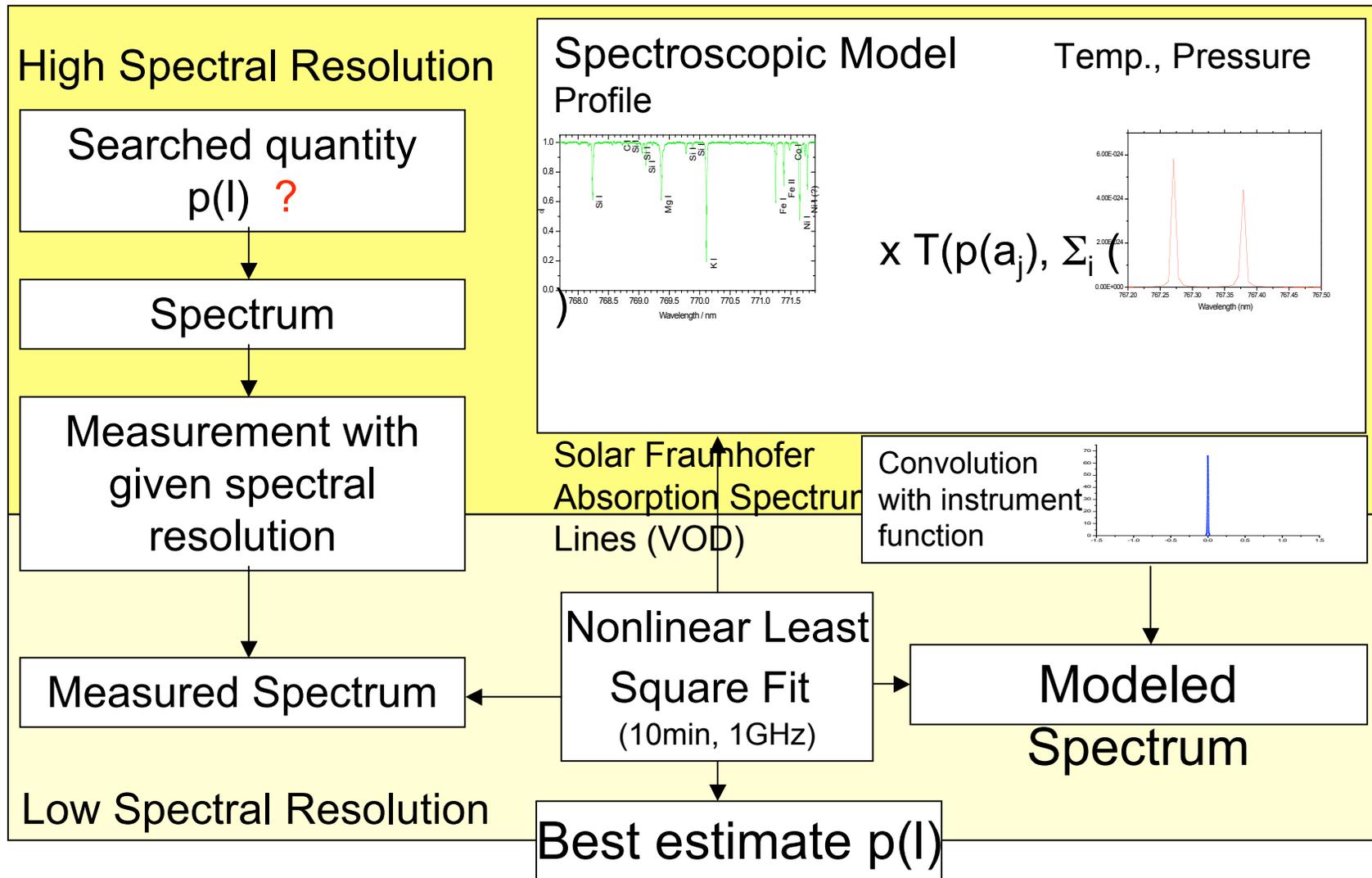
Instrumental Set-Up



- spectral resolution (FWHM) is presently limited to 0.013 nm (not line resolving)
- Integration time: < 15s (previously 900 s, but limited)
- by the spectral brightness of the sky)



Data Processing

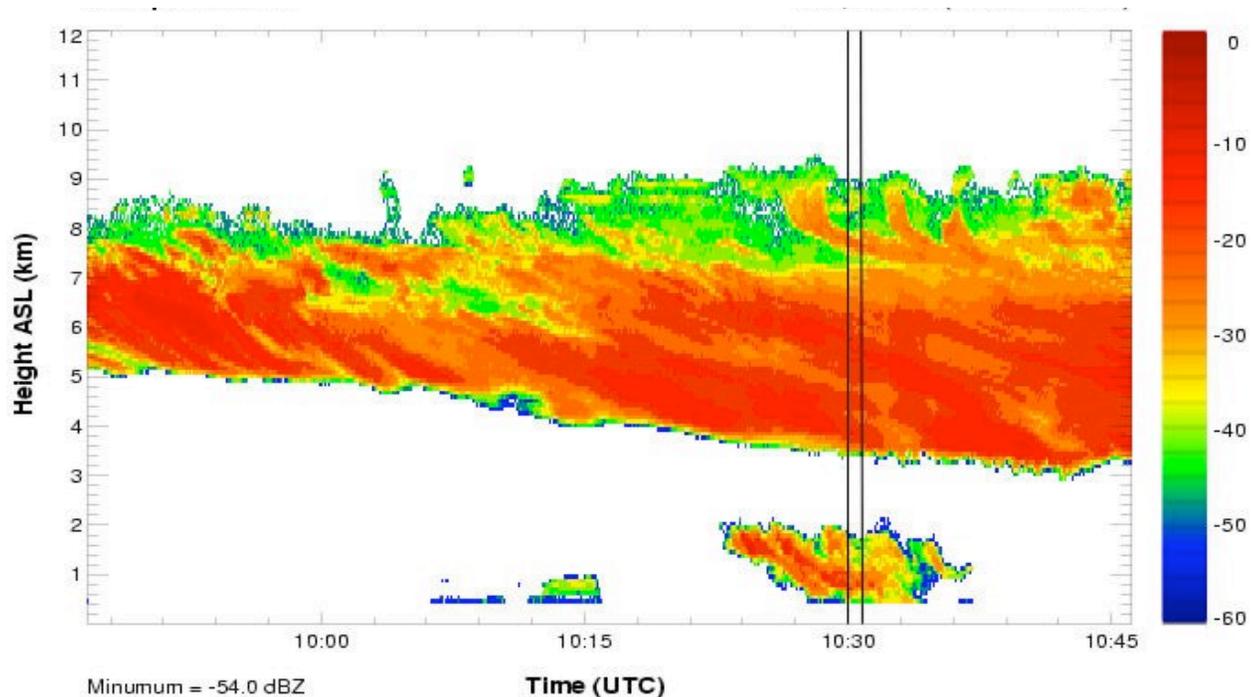


Measurements during BBC 2001

Cabauw/NL 51.971° N, 4.927° E in Sept. 2001 together with:

- GKSS 95 GHz Cloud Radar
- Lidar
- Microwave Radiometer
- Radio probes, aircraft in-situ instruments

Cloud structure (backscattering ratio measured by the 95 GHz GKSS Radar)
on Sept. 17, 2001, UT 9:45 - 10:45



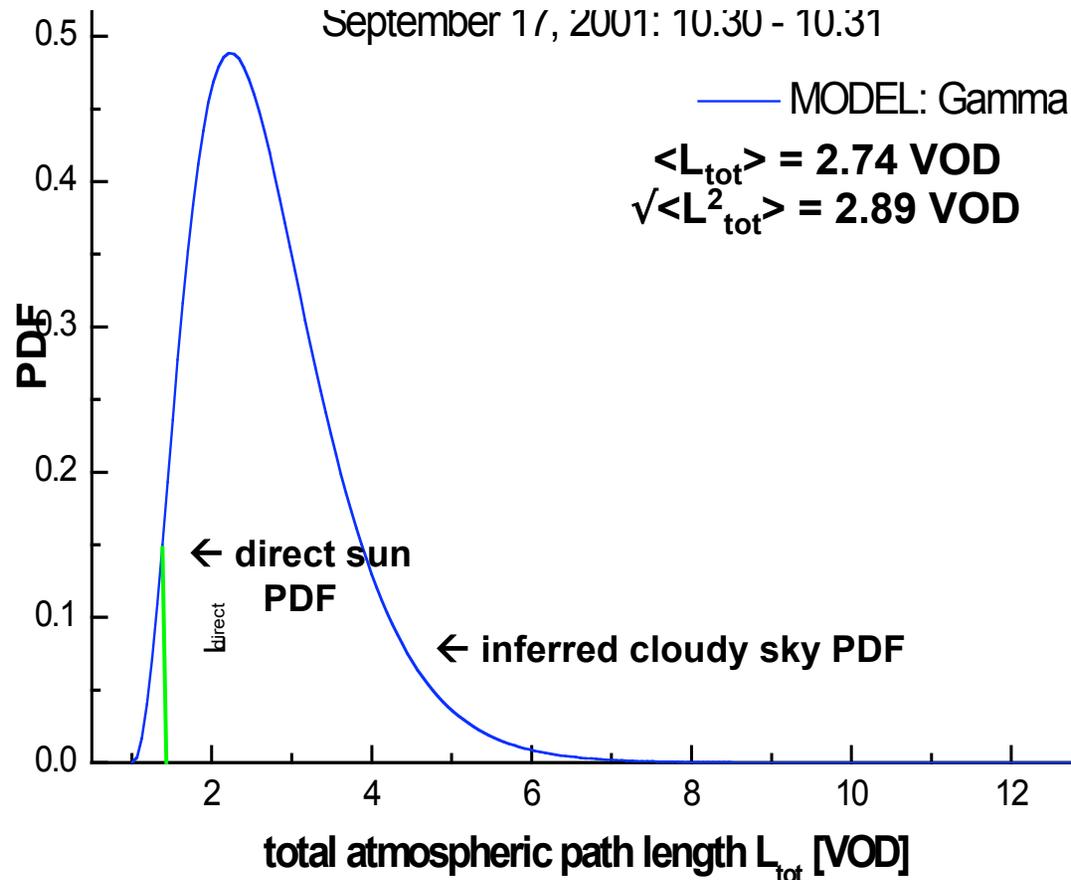
K. Pfeilsticker

Institut für Umweltphysik, University of Heidelberg,
Germany



Cloud Structure and Inferred PDF

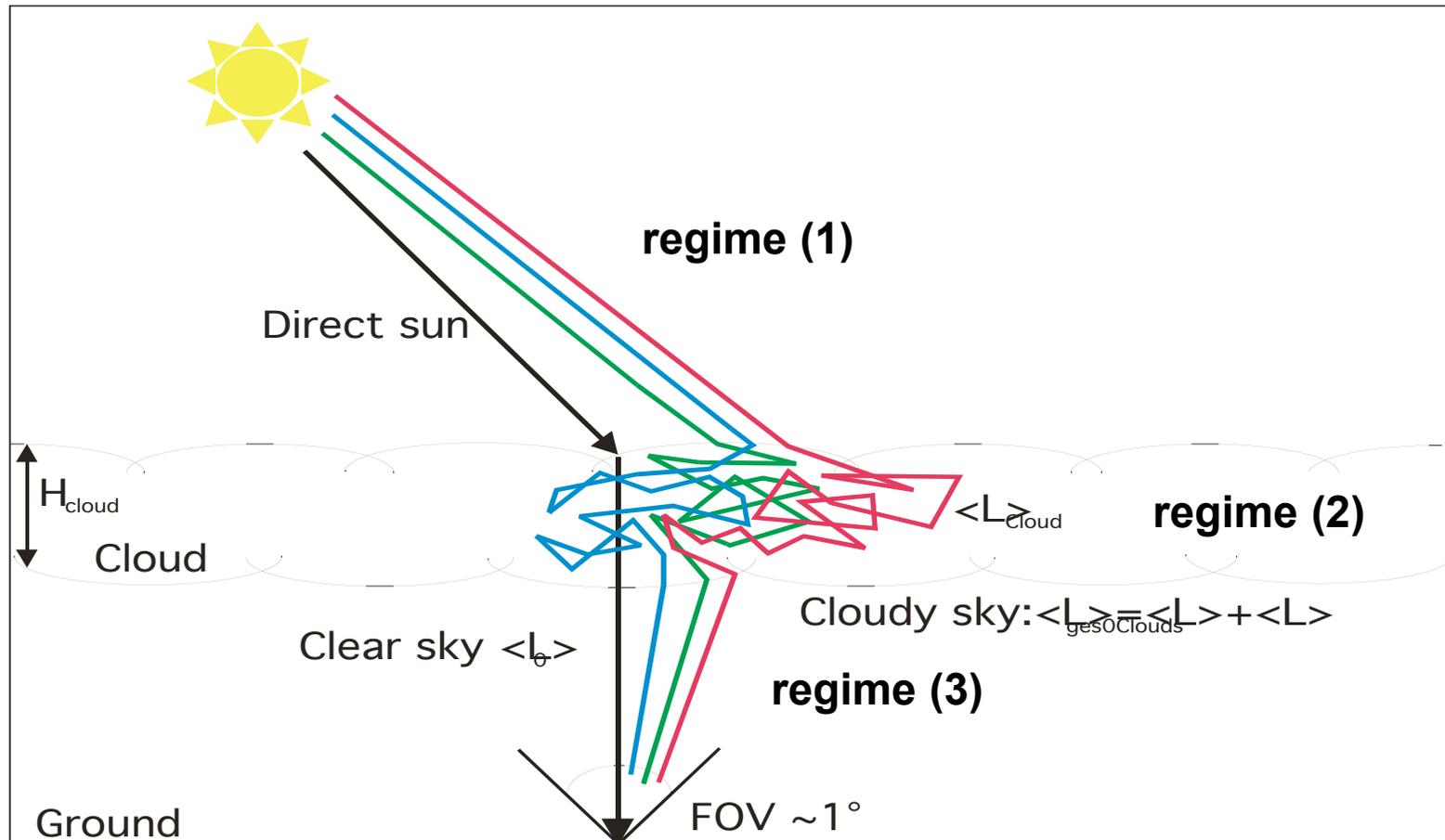
Inferred PDF assuming a Γ -type PDF distribution.



Note: The inferred first 2 PDF moments are given in units of a vertical optical density (VOD) for oxygen of the atmosphere



Idealized Scheme for Cloudy Sky RT



Attention: Oxygen A-band absorption measurement integrates over total atmospheric oxygen column \rightarrow hence in cloud pdf studies need corrections for the clear sky absorption !



From the total atmospheric paths ($\langle L_{\text{tot}} \rangle$ and $\langle L_{\text{tot}}^2 \rangle$)
to in-cloud paths ($\langle L_{\text{c}} \rangle$ and $\langle L_{\text{c}}^2 \rangle$)

regimes:

- above the cloud: $\langle L_1 \rangle = (L^\infty - H_{\text{cloud top}}) / \cos(\text{SZA})$ (typical values < 1 VOD)
- $\langle L_{\text{c}} \rangle$ (typical values > 2.5 VOD)
- below the cloud: $\langle L_3 \rangle = (L_{\text{cloud bottom}} - 0) \cdot (1 + 5A_g R_c / (1 - A_g R_c))$ (typical value < 0.5 VOD)

Corrections:

1st moment: $\langle L_{\text{c}} \rangle = \langle L_{\text{tot}} \rangle - \langle L_1 \rangle - \langle L_3 \rangle$

2nd moment: $\langle L_{\text{c}}^2 \rangle = \langle L_{\text{tot}}^2 \rangle - \langle L_{\text{tot}} \rangle^2 + \langle L_{\text{c}} \rangle^2$



Testing the pdf solution for photon diffusion through plan-parallel clouds and the anomalous diffusion (Lévy walk) model

- the first two moments -

1st moment: $\frac{\langle L_c \rangle}{\Delta H} = \{0.5 \cdot [1 + C_1(\varepsilon)] \cdot \tau_c^*\}^{(\alpha-1)}$

2nd moment: $\frac{\langle L_c^2 \rangle}{\Delta H^2} = \left\{ \frac{7}{20} \cdot [1 + C_2(\varepsilon)] \cdot \tau_c^* \right\}^{2(\alpha-1)}$

Davis&Marshak (2002)

Parameters: $\tau_c^* = (1 - g) \cdot \tau_c$

$$\varepsilon(\tau_c^*) = \frac{T}{R} = \frac{2 \cdot \text{const}}{\tau_c^*}$$

$$C_1(\varepsilon) = \frac{\varepsilon}{2} \cdot \frac{4 + 3\varepsilon}{1 + \varepsilon}$$

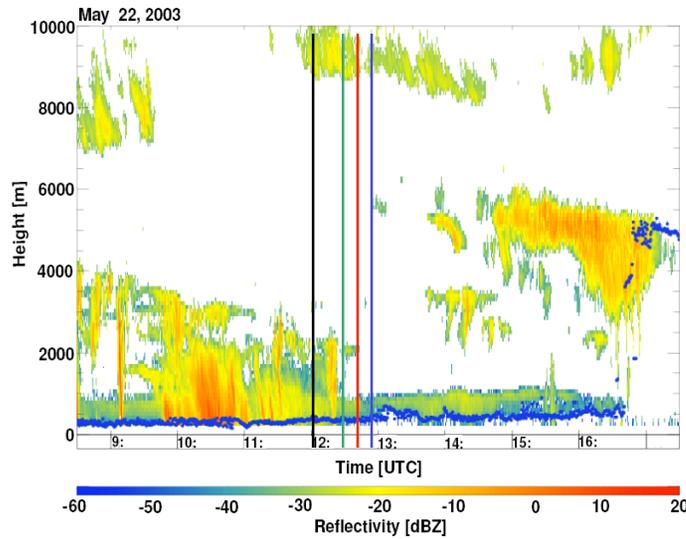
$$C_2(\varepsilon) = \frac{\varepsilon}{14} \cdot \frac{56 + 166\varepsilon + 150\varepsilon^2 + 45\varepsilon^3}{(1 + \varepsilon)^2}$$

Lévy index $1 \leq \alpha \leq 2$;

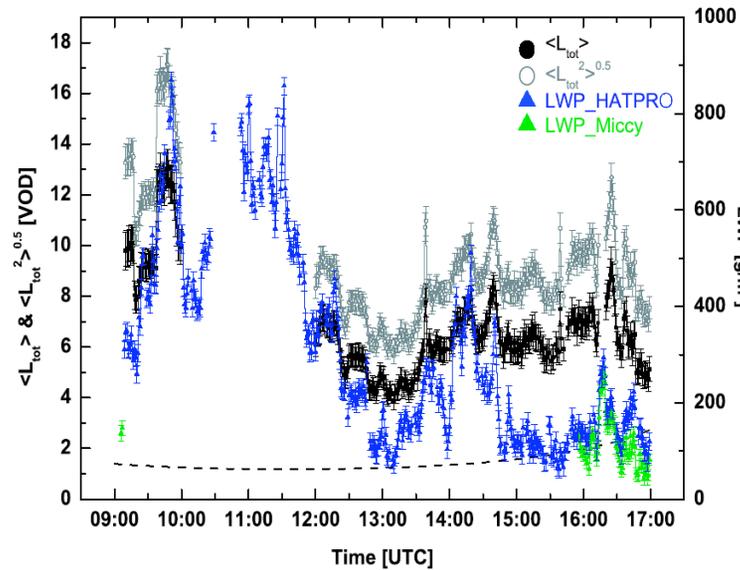
Davis&Marshak (1997)



Measurements over Cabauw on May 22, 2003



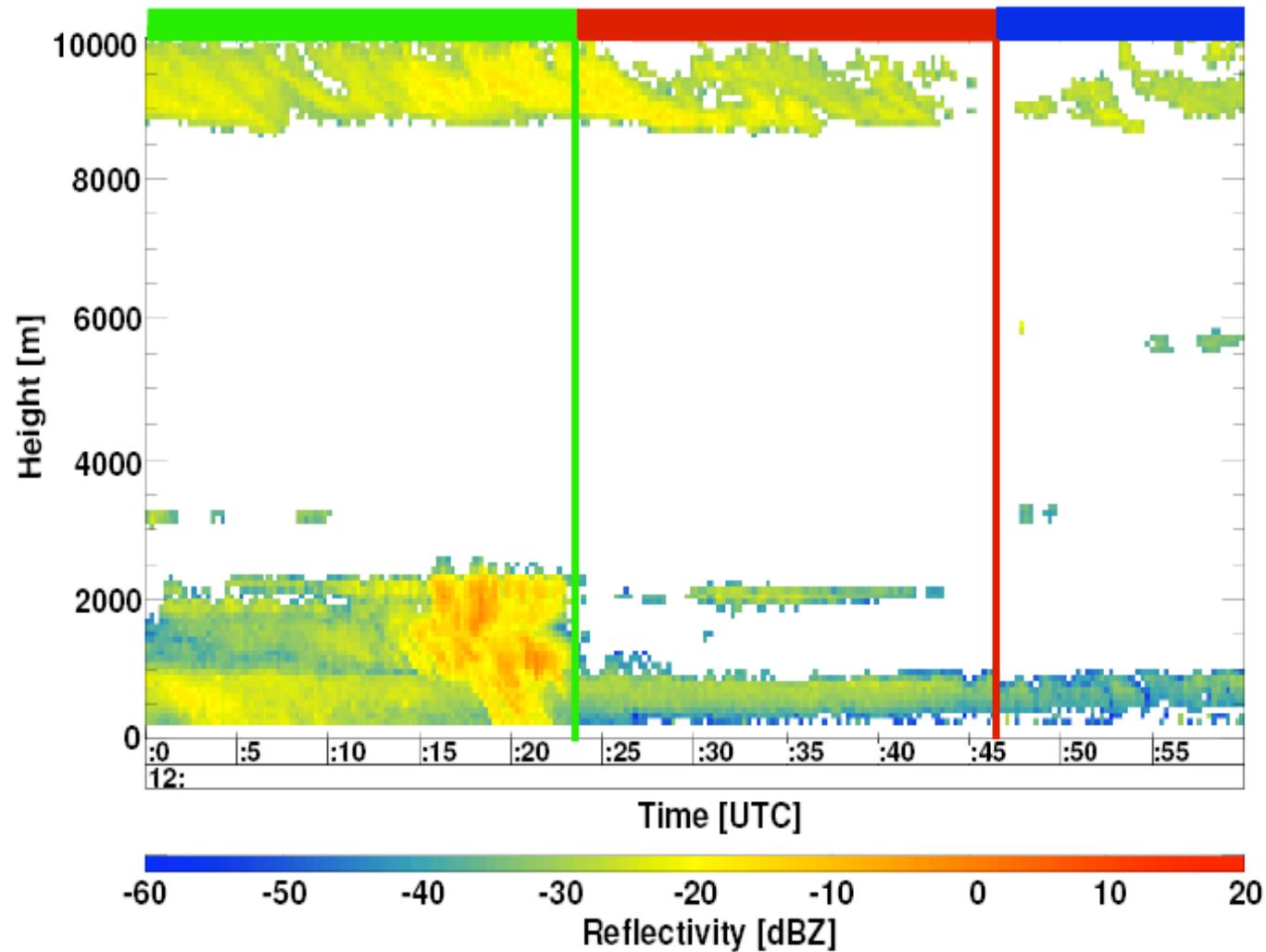
← radar reflectivities (KMNI, 35 Ghz)



← $\langle L_{tot} \rangle$, $\sqrt{\langle L_{tot}^2 \rangle}$, and LWP (KMNI, Uni Bonn)



Radar reflectivity measurements (KMNI, 35 Ghz) over Cabauw on May 22, 2003

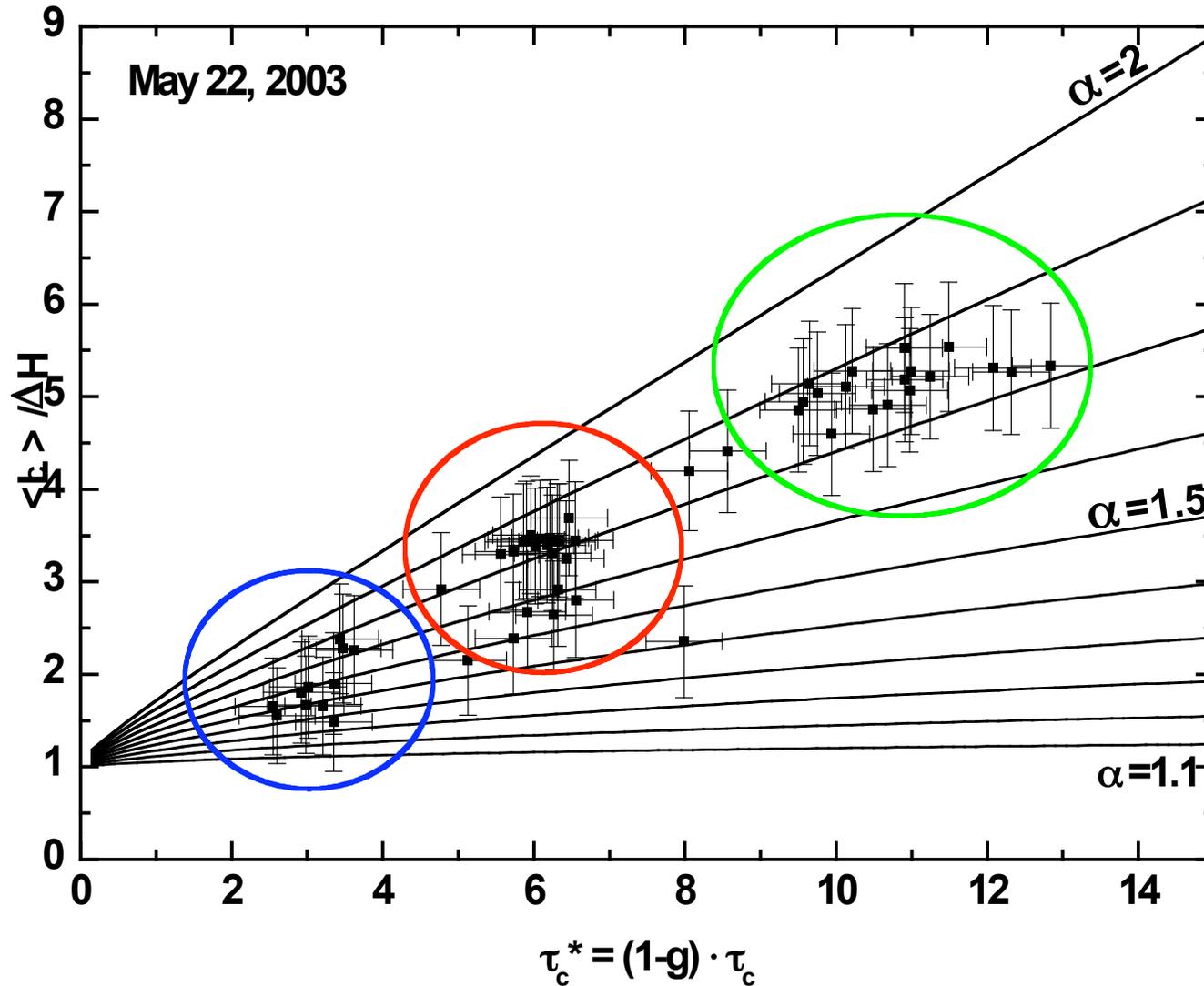


K. Pfeilsticker

Institut für Umweltphysik, University of Heidelberg,
Germany



Inferred Lévy Indices



Testing the pdf solution for photon diffusion through plan-parallel clouds and the Levy walk model (Davis&Marshak, 1997)

- ratio of 1st two moments -

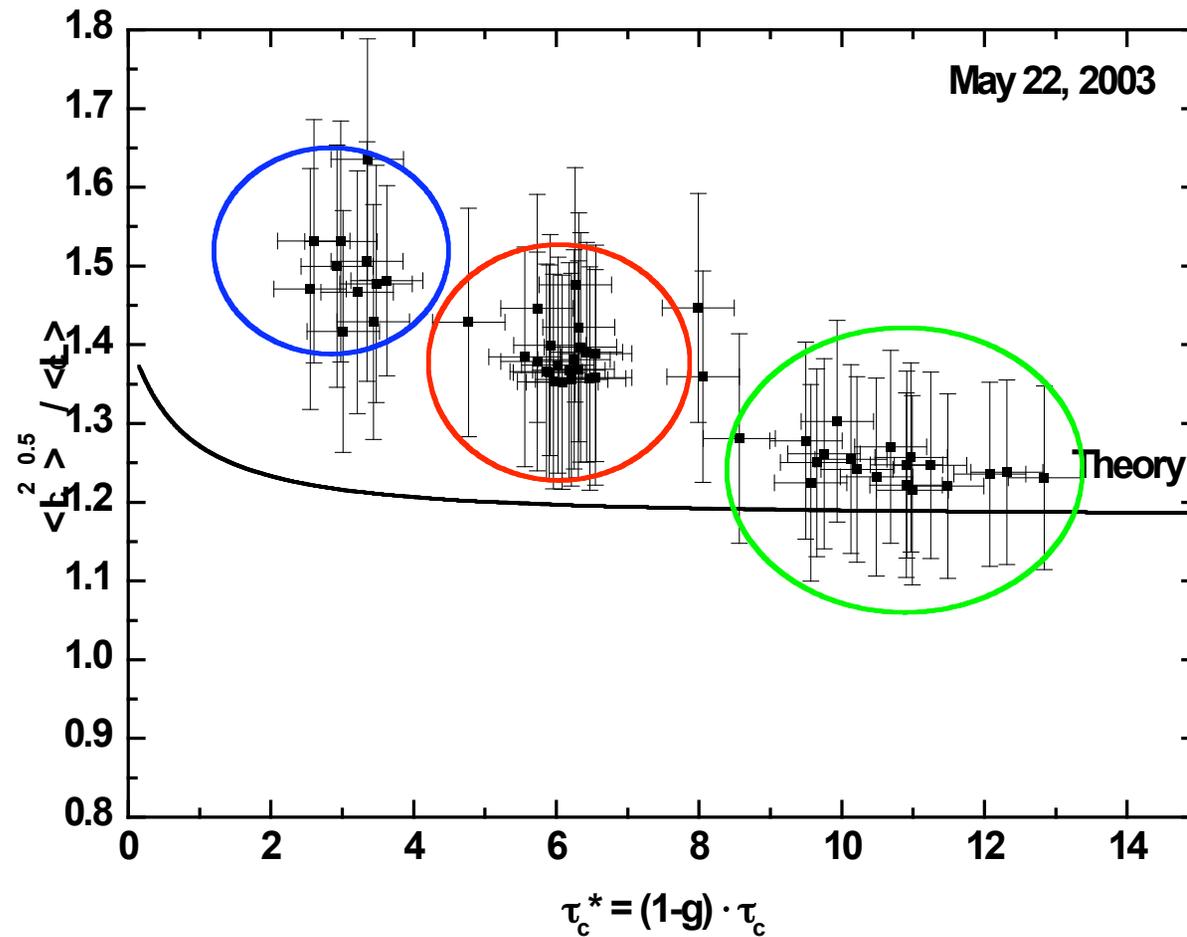
For $\alpha = 2$:

$$\frac{\sqrt{\langle L_c^2 \rangle}}{\langle L_c \rangle} = \sqrt{\frac{7}{5}} \cdot \frac{\sqrt{[1 + C_2(\varepsilon)]}}{[1 + C_1(\varepsilon)]} \in [1.18, 1.41]$$

Davis&Marshak (2002)



Ratio of the 1st two moments of inferred and predicted photon path lengths



Summary&Conclusion

- photon path PDFs ($\langle L_{\text{tot}} \rangle$, $\langle L_{\text{tot}}^2 \rangle$, $\langle L_c \rangle$ and $\langle L_o^{2c} \rangle$, can reliably be derived from oxygen A-band measurements (every 15 s).
- a wide range of PDF types occur, depending on the type of cloud cover.
- Gamma (log-normal) PDF is reasonably good approximations for photon path PDF's under slab like cloud covers ($\alpha = 2$).
- for more complicated cloud covers (c.f. multi-layer, broken cloud covers) anomalous diffusion approximation, c.f. Lévy type photon path PDFs are better suited ($\langle L \rangle \sim \tau^{\alpha-1}$ with $\alpha < 2$).
- Our measurements confirm the numerical values (prefactors) of the Davis&Marshak (2002) diffusion solution for plane-parallel clouds ($\alpha = 2$).

